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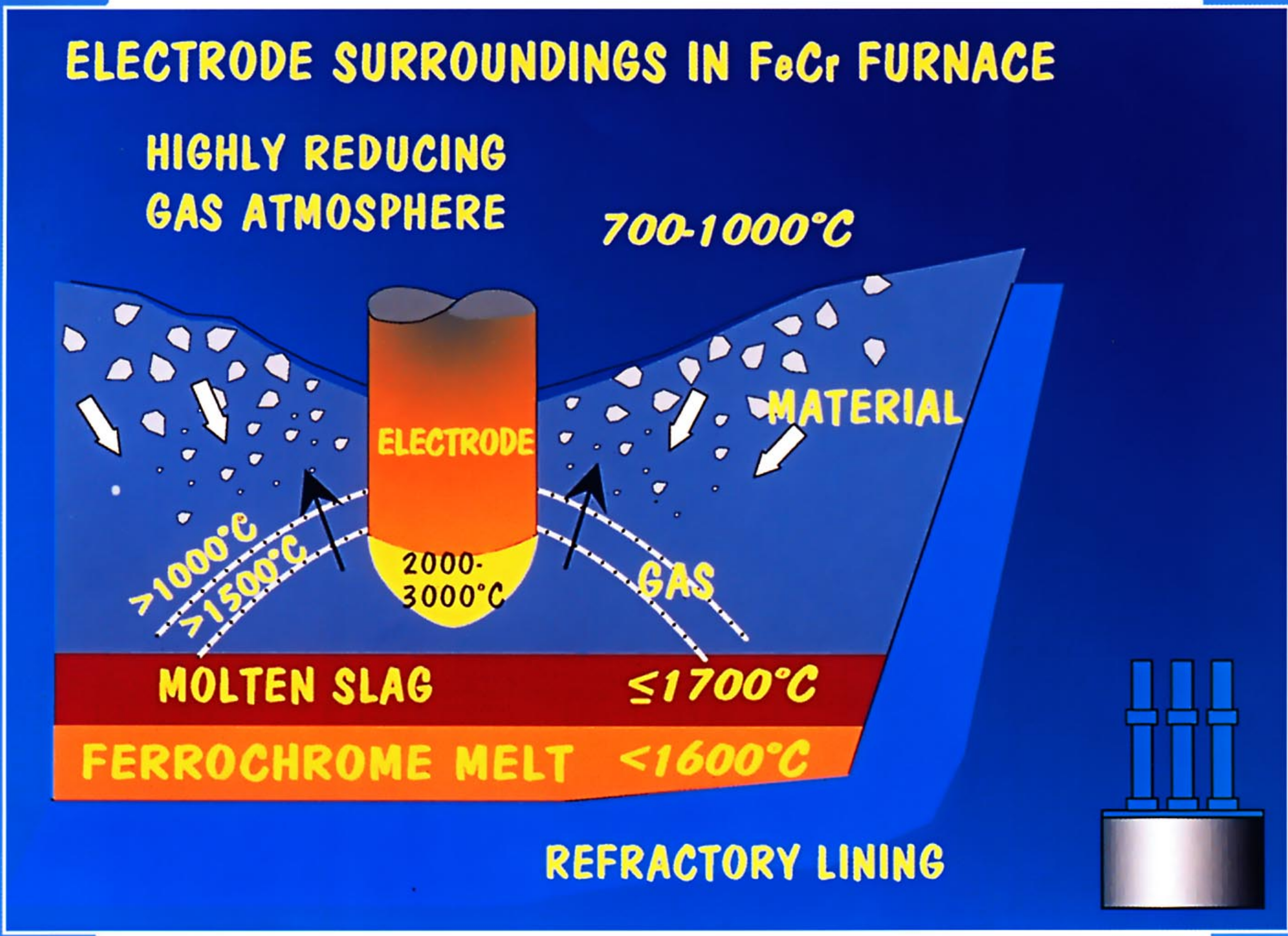
Marja Riekkola-Vanhanen

Finnish expert report on best available techniques in ferrochromium production



FINNISH ENVIRONMENT INSTITUTE

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Foreword

The European Council Directive on Integrated Pollution Prevention and Control (IPPC-Directive, 96/61/EC of September 24, 1996) is aimed at an integrated approach of prevention and control of pollution arising from categories of industrial activity listed in its Annex I. According to article 16.2 of the Directive the Commission shall organise an exchange of information between Member States and the industries concerned on best available techniques, associated monitoring, and developments in them. This information should lead to a European Best Available Techniques reference document (BREF) on each industrial sector.

One of the activities included in the Directive concerns the production of non-ferrous metals, according to the definition of category 2.5 (a) in Annex I: "Installations for the production of non-ferrous crude metals from ore, concentrates or secondary raw materials by metallurgical, chemical or electrolytic processes". These installations are part of the industrial sectors to be studied in 1998.

Within the above mentioned framework, the Finnish Environment Institute and Outokumpu Technology Oy have decided to contribute to the exchange of information in the European Union by making a study on Best Available Techniques for the primary production of non-ferrous metals. Outokumpu Research Oy has been requested to perform this study. Raimo Rantanen is responsible for the work. Pekka Niemelä from Outokumpu Chrome Oy has acted as technical expert in ferrochromium production. Marja Riekkola-Vanhanen has edited the report.

Primary non-ferrous metal production in Finland concerns only copper, nickel, zinc and ferrochromium. Gold and other precious metals are produced as by-products in the copper production. This report describes the production of ferrochromium. The primary copper, nickel and zinc productions are described in separate reports.

The main objective of this BAT report is to identify available techniques for the reduction of emissions and energy use of the ferrochromium production in Finland. The information presented is largely based on environmental permit applications, the corporate environmental programme and permit regulations concerning Outokumpu. Additional information concerning general issues of ferrochromium production and comparison of methods has been obtained from literature available.

The project has been guided by a steering group that provided comments on the draft reports and offered a platform for discussion on the scope, themes and results of the study. The steering group members represented the following organisations: Finnish Environment Institute, Southwest Finland Regional Environment Centre, Lapland Regional Environment Centre, Outokumpu Oyj, Outokumpu Technology Oy, Outokumpu Harjavalta Metals Oy, Outokumpu Zinc Oy and Outokumpu Chrome Oy.

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General Information

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Ferro-alloys are mostly used as master alloys in the iron and steel industry, because it is the most economic way to introduce an alloying element into the steel melt. Besides this, special ferro-alloys are also needed for the production of aluminium alloys and as starting material in specific chemical reactions.

As an additive in steel production, ferro-alloys improve the properties, in particular tensile, strength, wear and corrosion resistance. Improving the properties of steel by using ferro-alloys as an alloying element depends more or less on the following influences:

- a change in the chemical composition of the steel
- the removal or the tying up of harmful impurities such as oxygen, nitrogen, sulphur or hydrogen
- a change in the nature of solidification e.g. upon inoculation /1/.

Depending on the raw material that is used, the production of ferro-alloys can be carried out as a primary or secondary process. The principal chemistry of both processes can be shown as follows:

Primary processes:
Metal oxide + Reductant + (energy) $\rightarrow$ (ferro)metal + Reductant oxide

In general, the energy is electricity and carbon is used as reductant. Ferrochromium is produced by a primary process.

Secondary processes:
Metal scrap + iron scrap $\rightarrow$ ferro metal alloy.

Ferrochromium is only produced in Finland by Outokumpu Chrome Oy.

1.1 Occurrence of chrome ore

The only chrome mineral of economic importance for ferrochrome production is chromite, $FeO \cdot Cr_2O_3$, where FeO can be substituted by MgO and Cr_2O_3 by Fe_2O_3 and Al_2O_3. Over 80% of the world's known exploitable chromite resources are located in southern Africa. 30 % of natural chrome resources is lumpy ore, 70 % fine or friable ore. The fine ore cannot be fed directly to a submerged furnace without causing dangerous blow-outs and must therefore be agglomerated before charging in smelting furnaces.

The composition of chrome ore varies with the origin of the material. Major chrome ore producers are South Africa, Kazakhstan, India, Turkey, Zimbabwe, Finland and Brazil. Table 1 shows world chrome ore production figures for 1996.

Table 1. World chrome ore production in 1996 in ktonnes.

Country	Production
Albania	240
Kazakhstan	1,100
Finland	600
South Africa	4,980
Turkey	100
Zimbabwe	700
India	1,050
Brazil	450
Iran	180
Others	900

The ratio between chrome and iron in the ore controls the chrome content in the metal. In normal ores the ratio can vary between 1.5 and 3.5. The low ratio ores are used for producing charge chrome with a chrome content of 50–60 %. For producing ferrochrome carburé, with 4–6 %C and 65–70 % Cr, ores with higher ratios are used. With a ratio above 3 the ores can be used for producing low carbon ferrochrome. Table 2 shows the composition of ores from different origins.

Table 2. Compositions of different chromite lumpy ores.

Origin	Cr_2O_3	FeO	SiO_2	MgO	Al_2O_3	CaO	P	Ratio Cr:Fe
Kazakhstan	50.0	12.1	6.6	19.2	6.8	0.2	0.002	3.62
South Africa	39.5	22.4	8.0	11.2	14.4	1.0	0.004	1.55
Zimbabwe	48.5	11.6	6.1	14.8	12.3	1.8	0.002	3.68
Turkey	47.0	12.9	7.8	19.4	10.2	0.8	0.001	3.20
India	49.5	14.5	6.5	15.5	11.0	0.2	0.007	3.00
Albania	43.0	11.6	10.5	22.0	7.3	0.2	0.002	3.25
Finland	27.2	12.2	17.7	18.4	10.1	1.9	0.004	1.51
Philippines	32.1	12.8	4.6	17.5	30.0	0.6	—	2.20

The ratio between the chrome/iron oxides and the other oxides, mainly SiO_2, MgO and Al_2O_3 determines the amount of slag produced. The lower the ratio, the higher the slag production. A high slag production increases the amount of energy needed for smelting the ore.

The ratio between magnesium oxide and aluminium oxide influences the temperature in the furnace and, in consequence, also the carbon content of the metal. To reach an optimum temperature in the furnace, the slag may need adjustments with different additives. For the production of ferrochrome carburé, slow melting ore of refractory grade is used as part of the charge.

1.2 Production

Ferrochromium is a master alloy of iron and chromium, containing 45–80 % Cr and various amounts of iron, carbon and other elements. Ferrochromium alloys are classified by their carbon content and are known by their French names because the basic work in this field was mainly carried out in France:

- High carbon ferrochromium with 4–10 % C, “ferrochrome carburé”
- Medium carbon ferrochromium with 0.5–4 % C, “ferrochrome affiné”
- Low carbon ferrochromium with 0.01–0.5 % C, “ferrochrome suraffiné”.

The mechanical and chemical properties of steel can be improved by alloying it with ferrochromium. Chromium combined with nickel gives stainless steel excellent chemical resistance.

The oxides of iron and chromium present in the chromite ore can be readily reduced at high temperatures with carbon. Because of the tendency of chromium to form carbides, a carbon containing alloy is always obtained /2/.

Table 3 shows the production of high grade ferrochromium in the world in the years 1992 and 1996.

Table 3. Production of high carbon ferrochromium in tonnes /4/.

	1992	1996
Finland	187,000	236,082
France	6,694	
Italy	60,315	29,915
Norway	102,000	108,800
Spain	—	805
Sweden	133,000	133,110
Total W. Europe	489,109	508,712
Kazakhstan	329,937	285,885
Turkey	73,615	92,000
Others	337,048	113,627
Total E. Europe	740,600	491,512
South Africa	750,000	1,451,654
Zimbabwe	155,577	212,408
Total Africa	905,577	1,664,062
Brazil	85,085	85,324
USA	60,900	39,500
Others	2,171	—
Total America	148,156	124,824
China	240,000	—
India	239,521	261,666
Japan	266,300	193,100
Philippines	27,400	6,736
Total Asia	773,221	461,502
TOTAL	**3,056,663**	**3,250,612**

The consumption of stainless steel is increasing at an annual compound growth rate of 4 %. Almost 90 % of ferrochromium is used in stainless steel production. Chromium is the unique ingredient responsible for their corrosion and oxidation resistance. Chromium contents in stainless steels are normally in the range from 12 to 30 %.

The production of high carbon ferrochromium has decreased during recent years in the Philippines, Japan, India, China, Russia,Kazakhstan etc. They have been forced to reduce or suspend their production as the prices in the international market no longer covered their costs. The quantity of ferrochromium lost by suspension of operations at their electric furnaces is estimated to have reached 500,000–700,000 tonnes per year on the basis of their production capacities. These electric furnaces are very unlikely to resume operation. This situation is a feature of the depression throughout this market /4/.

It is anticipated that the production of stainless steel will grow. From this point of view, the demand for ferrochromium is forecast to increase. Outokumpu is the only fully integrated plant from chromite ore mine to finished stainless steel products in Europe.

2 Applied Processes and Techniques

This chapter describes the Finnish Outokumpu process to produce high carbon ferrochromium. A description is also given of the processes applied elsewhere.

2.1 Raw materials handling and storage

2.1.1 Raw materials

2.1.1.1 Reductants

In the smelting process energy is generated by electrical resistance heating controlled by the secondary voltage and the resistivity of the burden. The resistivity is greatly determined by the size and the type of the reductant.

The dominating reductants in the ferroalloy processes are various types of coke, coal, charcoal and wood chips. Metallurgical coke, of the same type used in blast furnaces, is the most common reductant in the ferrochrome process.

The coke is mainly transported by sea. Relatively small vessels are used to keep the coke storage as small as possible. The vessels are unloaded and the coke is transported from the harbours by truck in the same way as the ore. The coke is often stored outdoors causing variations in the moisture content as a consequence of rain- and snowfalls. As long as the moisture content is normal, between 10 and 20 %, handling can be done without dusting.

2.1.1.2 Slag additives

The chrome ores used in ferrochromium production contain not only reducible iron and chrome oxides but also slag-forming oxides. In order to obtain the right metal analysis, good metal recovery and satisfactory furnace operation, the slag needs to have :

- The right melting point for the actual metal quality
- A viscosity enabling easy tapping
- A good separation between slag and metal.

To optimise the slag composition, other minerals than chrome ore have to be added. Three important slag properties are results of the composition of the slag:

- **slag viscosity**, determines physical separation and recovery of metal from slag. High viscosity slags can cause foaming problems in furnace operation
- **slag resistivity**, helps to determine electrode penetration and power input to the furnace with more resistive slags allowing deeper penetration, higher voltage operation and greater power inputs
- **slag liquidus**, determines overall operating temperature and degree of superheat to the melt.

The main slag additives used are quartzite, aluminium oxide containing material to compensate for the high magnesium content in certain ores, and magnesium and calcium oxide containing material for aluminium rich ores.

2.1.2 Transport of raw materials from mine/harbour to plant

The production of ferrochromium involves considerable transportation. Chrome ore is produced in mines all over the world. Finland is the only country in Western Europe where ore from a local mine is used. Coke is mainly produced in Europe and shipped by vessels to harbours near the ferrochromium works. Both these raw materials are weighed and sampled in connection with the transport to determine the content of both main components and impurities.

The loading and unloading of trucks as well as the road transport create noise and dust. The truck transport also consumes energy and causes traffic emissions.

Excessive dusting is prevented by water spraying of dry fine grained raw material or by transport with covered trucks. Most transport companies are currently working with different environmental management systems, involving environmental classification of vehicles and fuels.

2.1.3 Storage of raw materials before use

As a consequence of the size of the operation and in many cases the long distance between the ferrochrome plant and the raw material suppliers, the material in storage has to cover several months of production. The raw materials are preferably stored on hard surfaces to prevent contamination. Indoor storage is the best, if possible. The loading and unloading of rail cars and trucks using crane grips, front end loaders and dumper trucks is preferred in an effort to prevent spillage and dusting. The amount of material loss caused by handling and storing of raw materials is estimated at less than 0.2 %.

2.2 Pre-processing

2.2.1 Handling of lumpy chrome ore

For charging semi-closed furnaces the maximum size of chrome ore is about 150 mm. The lumpy chrome ore fed to closed ferrochromium furnaces has a maximum size in the range of 65–80 mm.

2.2.2 Briquetting

The raw material for briquettes are chrome ore fines and concentrates together with suitable binding materials. The chrome ore is screened and dried. After adding binders and water the mixture is fed into a briquetting press. The binding material must make the briquettes so that they have sufficient green strength, which allows them to be handled easily and to remain unbroken when they are charged into the submerged arc-furnace. The briquettes should also have good high-temperature strength so that they do not disintegrate before the reduction process is well under way or until the chromite sinters at about 1300 °C. It is also an advantage if the briquettes are weather-proof.

Molasses, lime, sodium silicate, steel slag or cement, silica fume and various activators and fluxes are used as binders. Pitch can be added to improve green strength.

Before briquetting, efficient mixing needs to be carried out. In some cases the mixing is done in two steps, where solid binders are mixed with the ore in the first mixer and liquid binders are mixed in the second.

2.2.3 Pelletizing-sintering

The raw material for the sintering plant is chromite concentrate or fines. In the sintering plant the concentrate is ground in a ball mill, filtered by capillary or drum filters, pelletised by a rotary drum or disc and finally sintered in a steel belt furnace or shaft furnace. The product from the sintering furnace is hard, porous chromite pellets with constant physical and chemical properties suitable for ferrochromium smelting furnaces.

Sintering means heating pelletised chromite up to a high temperature in which the chromite grains in the pellets are bound together with molten silicates. This forms a strong structure which can withstand mechanical and thermal treatment. In addition to the chromite, fine coke and bentonite are used in sintering. Coke is used as the main energy source in sintering. Bentonite is used as the binding agent in the pelletising and in the drying stage of the sintering.

2.2.4 Sintering

Sintering in a grate furnace is an agglomeration process suitable for ores with a particle size in the range of 0.1–3 mm. A large proportion of particles below 0.1 mm should be avoided, as this will reduce the permeability of the sinter bed and thus reduce productivity. A high proportion of coarse particles will, on the other hand, tend to give a mechanically weak sinter.

The main binding mechanism in ore sintering is achieved by bringing the ore up to a temperature where the gangue minerals start to melt, whereby individual particles are fused together in a matrix of partly molten “slag”. Coke breeze is used as fuel and sometimes fluxes to ease the slag matrix formation. The sinter cake from the grate is crushed to a suitable size and cooled before use in smelting.

2.2.5 Direct processing of fines

When direct current arc technology is used for smelting chrome ore to ferrochromium the furnace can operate with ore fines without prior agglomeration. The principle is a transferred-arc open bath process where the furnace is equipped with a single hollow graphite electrode for the charging of chrome ore fines, reductant fines and fluxes.

The chrome ore can be efficiently preheated for example in a fluidised bed system. Here too the use of off-gas energy can decrease the electric energy consumption per unit produced.

2.2.6 Coke drying

The moisture of the coke used in the smelting process can be as high as 10–20 % when the coke is wet quenched. High moisture contents in the raw materials are generally harmful to the smelting process, particularly in closed furnaces, and also lead to increased power and coke consumption. Coke drying is a way of ensuring the right amount of carbon in a smelting charge. Normally a coke mix from different sources is used for drying. Drying can be done in a simplified rotary kiln, or in a shaft furnace, to moisture levels less than 5 % using furnace CO-gas as fuel.

2.2.7 Weighing and feed control system

The raw materials are with few exceptions stored outdoors. As soon as the charge composition is known, the materials are transported to loading hoppers from which the materials are forwarded by conveyer belts to raw material bins. Conveyer belts are covered to avoid dusting.

From the raw material bins the materials are fed batchwise into weighing hoppers. A computer system controls weighing. Scales with automatic taring and overshoot compensation and a system allowing for moisture corrections minimise weighing system errors in controlling the ore/coke ratio.

Several batches simultaneously in transition and multiple furnace operations are also typical features of an advanced charging system. After weighing the batches are transported to the furnace hoppers by conveyor.

2.3 Core processes

There are approximately 155 submerged arc furnaces for high carbon or charge grade ferrochromium production in the world and two D.C. plasma furnaces. Their transformer capacities are 3–105 MVA and production capacities 5,000–160,000 t/a. High carbon ferrochromium production was 3.251 million tonnes in 1996. The proportion produced in Europe was 15.6 %.

2.3.1 High carbon ferrochromium production

The production of ferrochromium is an energy-intensive process. The processes in production today use electricity and fossil fuels. Factors affecting energy consumption include the quality of raw materials and their pre-treatment before smelting, the utilisation of reaction energies and heat contents from the processes.

The chromite raw materials for ferrochromium production are used as lumpy ore, upgraded lumpy ore, ore fines and concentrates. To convert ore fines and concentrates to more furnaceable lumpy material, these materials may be sintered directly or agglomerated by briquetting, micropelletising and pelletising and sintering. The majority of chrome ore produced in the world is fine ore. Lumpy ore prices are higher than fine ore prices.

Ferrochromium is produced pyrometallurgically by carbothermic reduction of chromite and is thus high in carbon. The main reaction is

$$Cr_2O_3 + 3C \rightarrow 2Cr + 3CO \qquad (1)$$

At the same time iron oxides and a little silica are also reduced. A considerable amount of the chromium and iron is in the form of carbides.

Coke (charcoal, coal) is used as a reductant. Quartzite, bauxite, olivine, dolomite, limestone and calcite are used as slag additives. The charge is dosed into the smelting furnace either cold, preheated or prereduced.

The smelting of chromite ores and concentrates is dominated by the electric submerged arc furnace and it has become entrenched as the recognised production unit for ferrochromium alloys. The submerged arc furnaces are open, semi-closed or closed. D.C. plasma smelting is used for minor capacity production.

2.3.1.1 Preheating

The electricity consumption of ferrochromium smelting can be decreased by preheating the feed materials. In the Outokumpu process the charge is preheated by the CO-gas generated in smelting, either in static preheating equipment of shaft type or in a rotary kiln. Through preheating the charge, it has been possible to cut the consumption of electric energy by 250–330 MJ per 100 °C increase in preheating temperature/tonne FeCr.

By preheating the charge at 700 °C the moisture and a major part of the volatiles can be removed before the material is charged into the electric furnace. Thus the formation of reduction gases in the submerged arc furnace is stable.

Outokumpu preheating technology is used in seven processes in the world. Four of them are shaft type kilns. One new shaft kiln is in the course of construction. The operation time of the shaft kiln process is high.

2.3.1.2 Prereduction

In the Showa Denko process, chrome ore fines are milled in a rod mill, pelletised with coke as reductant, dried in a travelling grate kiln, and fired in a rotary kiln to approximately 1,400 °C. The kiln is heated by a pulverised coal/CO/oil burner. Even after exhaust gas from the rotary kiln and the rotary dryer, there is heat energy left. It is used for a waste heat boiler to generate steam. The pellets achieve approximately 60 per cent total metallisation of chromium and iron. Reduced pellets to be discharged from the rotary kiln are stored in a completely sealed surge hopper designed to prevent re-oxidation. Reduced hot pellets are discharged from the surge hopper and supplied to the electric furnace after being combined with coke and flux through a feed bin. The process uses ore fines. Only moderate levels of metallisation are achieved. The weakness is an accretion formation in the kiln. There are two such processes in use in the world.

The other used prereduction technology is the Krupp-Codir (CDR) process. It also uses unagglomerated ore fines. The self-agglomeration of the fines happens in the rotary kiln in the high temperature zone. A temperature of 1,500°C has been used. The kiln feed consists of chromite concentrate, coal and flux. Coal is used as both energy source and reductant. The metallisation degree is 80–90 per cent. The difficulties are an accretion formation, suitable refractories and maintaining a constant degree of prereduction and agglomeration. There is one CDR process in use in the world.

2.3.1.3 Smelting

In the production of ferrochromium, the most important stage is the reduction of chromite. The reduction process is a typical high-temperature process. The final reduction is made by electrical power or fossil fuel. The reduction rate and chromium recovery depend on temperature, charge material sizes, chromite particle sizes and specific surface areas. The chromite itself and the feed mixture should have high melting points for the correct operation of the submerged arc furnace.

Ferrochromium is produced in open, semiclosed or closed submerged arc furnaces and D.C. plasma furnaces. Charge is cold, preheated or prereduced.

The submerged arc furnaces include three-phase A.C. operations with three Söderberg electrodes and energy generation by electric resistance heating. Close control of the charge composition and its sizing, as well as of the slag composition are essential for effective operation of the submerged arc furnace. The D.C. arc furnace includes a single central hollow graphite electrode. It operates with ore fines without prior agglomeration and cheaper reductants. The thermal efficiency is left lower than in a submerged arc furnace due to greater radiation loss and higher temperature gases leaving the system.

The totally closed electric furnace is covered by a water-cooled refractory or metal roof. The smelting charge flows continuously from the tubes to the hearth so that the material in the tubes at the same time forms a gas tight seal. Chromite is reduced both in solid and liquid state. Smelted products go on to the bottom of the furnace.

The smelting practice may be based on resistance or current control so that the electrodes are lifted and lowered when necessary to keep resistance or current constant. This means certain requirements to the electrode sealings to prevent air leakage into the furnace. Alternatively is the practice where the electrodes move only during slipping and stand otherwise in place.

The smelting process produces metal and slag, and CO rich off-gas. The products are tapped at regular intervals of 2–4 hours. The produced metal is of charge chrome or high carbon ferrochrome with chrome content 50–70 %, carbon 4–9 % and silicon 0.5–6 %. The slag consists mainly of SiO_2, Al_2O_3 and MgO in different phases but also smaller amounts of CaO, chromium and iron oxides and metal fragments. The chrome content in slag is 2–12 %, in oxide and metal form. The slag/metal amount ratio in smelting varies from 1.0 to 1.8, depending on raw materials.

The solid products obtained from the smelting of ferrochromium are metal, slag and dust. In open top and semiclosed furnaces the dust is collected as such in a bag filter plant, whereas in a closed top and plasma furnace, the dust is scrubbed in a venturi system and is produced as a slurry.

CO-gas

The reduction develops 650–750 Nm^3/tonne FeCr of CO-gas, if the furnace is closed and the furnace sealing is good. The off-gas volume from the semi-closed furnace is 10,000–15,000 Nm^3/tonne FeCr and from the open furnace 50,000–55,000 Nm^3/tonne FeCr. If the furnace is open the reaction energy of the reduction is lost and cannot be utilised as fuel later.

The CO-gas formed during reduction is sucked out from the closed furnace through two take-offs to wetting scrubbers. In normal operation both scrubbers operate at the same time, but the furnace can operate with one scrubber alone at full furnace power. There are different high and low pressure scrubbers in use (Outokumpu, Warkaus, Fläkt, Howden). The specific consumption of water per m^3 of gas will vary widely with scrubber type. Any possible extra CO-gas is ducted out to the CO-gas stack and burned there.

The CO-gas can be transferred by means of pipelines in the plant area as easily as any fuel gas. In the best case all the CO-gas is utilised as fuel. It can be used by direct burning in the integrated ferrochromium and stainless steel production, in the neighbouring steel works or for recovering energy. In the energy recovery process of a semi-closed furnace, CO-gas from the smelting furnace burns in air thus creating a hot off-gas. The furnaces are equipped with integrated energy recovery systems. Superheated steam is sold to the neighbouring mills for use in their process and/or electricity production in a back pressure turbine. Hot water is sold for local heating needs. Only closed furnaces and furnaces with closable hoods offer favourable possibilities for energy recovery. The CO_2-emission, 600–700 Nm^3/tonne FeCr after combustion, is the lowest in the closed furnace process.

Treatment of process waters

Water from the gas scrubbers will contain from 1 g/litre upwards of suspended solids. These must be removed before the water is recirculated or discharged.

The contaminated water is normally pumped to a thickener to settle out the suspended solids. In some cases settling ponds are used, or a combination of thickeners and settling ponds. Since the particles mostly are extremely fine, it may be necessary to add a flocculant to assist settling in thickeners.

The settled sludge can be de-watered on vacuum filters, press filters, in centrifuges or by other methods to enable transport to, and storage in a deposit, or the slurry under-flow from the thickener can be transported to settling ponds. The main constituents of the sludge are oxides and hydroxides of Mg, Si, Ca and Al. The content of Cr_2O_3 varies between 1 and 10 %, Zn less than 5 %, and the sludge will usually contain less than 1 % PAH.

The extent of polishing of the process water bleed is very much dependent on the recipient. Cyanides are very readily oxidised in sea water, but more stable and potentially harmful in fresh or brackish water.

2.4 Post furnace operations

2.4.1 Tapping arrangements and tapping equipment

The tapping sequence can follow either tapping at fixed intervals or when a fixed quantity of electricity is reached since the last tapping. The design of the tapping arrangements may vary greatly between plants. The type and function of the equipment will, however, to a large extent be common to all plants.

2.4.1.1 Tapholes

Ferrochrome furnaces will have at least one taphole, i.e. a specially designed refractory inset in the furnace side-wall with a circular opening, which will be plugged with refractory clay between each tap. Slag and metal is tapped through the same taphole.

2.4.1.2 Tapping launders

On all furnaces there will be a tapping launder or tapping spout, channelling tapped metal and slag to the tapping vessels. The length and design of the launder or spout will vary considerably with the total tapping arrangement design. The most widely used practice is to tap slag and metal into a common ladle, with overflow from this ladle.

2.4.1.3 Tapping equipment

The taphole is normally opened using a pneumatic or hydraulic drill. This will be mounted on an overhead rail car, moveable arm or similar, which enables the drill to be moved into position for each taphole opening. Oxygen lancing is also used for taphole opening, either as the only method or as a back-up or complement to drilling.

2.4.1.4 Metal and slag vessels

The most widely used metal vessel is a ladle with welded steel shell with an inside lining of refractory materials. Refractory bricks are traditionally used as lining material, but monolithic castable refractories have been increasingly used in the last few years. The metal is cast from the ladle or pot after the tapping is finished.

2.4.1.5 Vessel arrangement

The most frequently used arrangement for ferrochrome is cascade tapping. This means that slag and metal are tapped together into a metal vessel. The lower density slag will float at the top, eventually overflow through the ladle spout to the slag-pot, directly or via a secondary launder to a slag pit, granulating basin or other slag vessel. If slag-pots are used, there may be up to six or seven vessels in the cascade. Where ladle volumes are small compared to the tapped metal volumes, two metal ladles can be used in the cascade.

2.4.1.6 Tapping fume collection and cleaning

Due to the highly different tapping arrangements, the design of fume collection equipment and the fume collection efficiency will vary quite widely. Tapping fumes consist of fumes from oxygen lancing, dust from drilling, fumes from the vaporised slugs if a tapping gun is used and fumes from all exposed metal and slag surfaces. These fumes will mainly be oxides of the metals involved in the smelting process. There may also be smoke from burning coke on top of the ladles and smoke from the taphole clay, mainly from the binder. In addition there may be carbon dioxide from burning coke or reactions in the ladles, and traces of sulphur dioxide released from the slag.

Efficient collection of all the fumes and smoke from tapping will always be difficult. Tapping equipment like guns and drills, traffic by cranes and other vehicles will usually be in the way and make it impossible to design extraction hoods, ducts etc. which are 100 per cent efficient. Therefore, it is inevitable that part of the uncollected fumes, dust and smoke will leave the furnace building with the ventilation air.

The cleaning equipment most frequently used today for tapping fumes is the bag filter. This can be a separate filter for the tapping fumes, or a filter which also cleans the fumes from metal casting or the furnace off-gas from open or semi-closed furnaces. A cyclone or other low efficiency dust catcher is sometimes used before the baghouse to prevent sparks or burning material from entering the filter.

Wet scrubbing of different types can also be used. The scrubber water will in this case have to be treated before recycling or before being discharged.

2.4.2 Secondary slag/metal separation

The stainless steel producers, which are the ferrochrome producers main customers, demand a slag-free alloy. In most cases, a secondary slag/metal separation is therefore required. The exception may be where a skimmer is used in the launder, but also in this case some slag may follow the metal through the skimmer, particularly if the skimmer is not properly built.

2.4.2.1 Slag skimming machine

The normal practice for secondary slag removal where cascade tapping is used, is the use of slag skimming machine. If the slag layer on top of the metal is thick, some slag will be poured off prior to skimming. The slag is removed until the metal surface in the ladle is virtually slag free.

2.4.2.2 Slag skimming during casting

Slag skimming during casting is not used as the only method of slag/metal separation, but sometimes as a complement to other methods to ensure very clean metal when required. The skimmer is similar in principle to the launder skimmer, but usually without the slag launder after the skimmer.

2.4.3 Use of molten metal and metal casting

2.4.3.1 Use of molten ferrochrome in stainless steel production

The liquid metal can only be used directly in steel production in the rare case that the alloy producer is integrated with a stainless steel producer. This has the advantage that later steps in the alloy production can be minimised, and also that the heat content of the liquid metal can be utilized. But even in integrated plants, some ferrochrome must be added to the steel in solid form, for instance for the final adjustment of analysis before casting the steel. In addition it will be impossible in practice to balance exactly ferrochromium production with steel plant demand at all times. Metal casting facilities must therefore also be available to the integrated ferrochrome producer. Bed casting and layer casting are the most frequent methods of casting ferrochrome because of the simplicity and low cost of the methods.

2.4.3.2 Bed casting methods

All bed casting methods are based on the same basic principle: The metal is poured into beds made up of a bedding material and left there to solidify. After solidification the solid alloy cakes are removed, and the bed is made ready for pouring again.

2.4.3.3 Layer or stack casting

Layer casting, also known as stack casting, is another widely used method for several ferro-alloys. In a sense this is also a bed casting method, as the metal is poured into a bed, limited on three sides by walls made of refractory concrete, cast iron or cast steel plates or steel slabs, and on the fourth side by a barrier of alloy fines or other bedding material. The bottom will be of the same materials as used in the three walls, but with the addition of a layer of metal fines or bedding material for heat protection. In this bed several casts are made on top of each other, and with sufficient time between each cast to allow solidification and some cooling.

2.4.3.4 Granulation

Granulation is a fairly recent development for ferroalloys. The basic principle involves making individual droplets of the alloy, and using water to quench it. Only two of the existing methods for ferroalloy granulation are known to be presently used in full scale production of ferrochromium: the Granshot and the CMI methods.

In the Uddeholm Granshot method, metal is poured on a refractory plate. This breaks up the metal stream into an umbrella of individual droplets, which falls into a water tank.

In the CMI method metal is poured via a launder and metal distributor into a water tank. Water jets under the surface of the water in the tank will break up the stream of metal into droplets.

In the Elkem granulating process, a sufficiently thin and long stream of metal to allow "distortion" of the stream and starting droplet formation, is channelled directly into a water tank, where the metal will break up into discrete droplets.

In all three processes, the granules are brought up from the tank by a steel conveyor while still hot enough to dry from the internal heat in the granules.

2.4.4 Slag handling

All slag will contain some metal, but often in the bulk of the slag only as small, and relatively widely spaced, microscopic droplets. The amount of metal in the slag is very much influenced by the tapping arrangement. The tapping arrangement and tapping and casting practice are therefore important factors in deciding the overall slag handling practice.

2.4.4.1 Non recovery slag and recovery slag

In all ferrochrome plants there is a distinction between non-recovery slag and recovery slag. The non-recovery slag refers to slag with such a low metal content that it is not deemed worth reclaiming, recovery slag has a sufficiently high metal content to allow recirculation or alloy recovery. The definition of what constitutes non-recovery slag and recovery slag, however, varies from plant to plant, and will depend on such factors as availability of reclamation technology, availability of investment capital for such technology, the market for sale of slag, available space for a reclamation plant etc.

2.4.4.2 Slag handling methods

Several slag handling methods are in use, depending mainly on the tapping arrangement.

The slag from the launder slag skimmer or the overflow from the metal ladle can be channelled directly to a slag pit, usually via a launder. It is allowed to cool in this pit, also cooled by water spraying, before being broken up by front end loader and transported away.

The slag flow can also go to a granulation basin, where water jets break up the slag flow into small fragments and quench the slag. Depending on the composition of the slag, quenching will often give a high proportion of hard glass phase in the slag. If a relatively shallow basin is used, it can be emptied by front end loader. Pumping or use of grab are other possible methods.

Where there is not enough available space for a slag pit or granulating basin, liquid slag transport is commonly used, in slag pots or in a slag bed on a movable platform. The slag is then transported by special vehicles to a teeming station with several teeming positions. Pouring is done in one position, while cooling, usually by water sprays, and breaking up cooled slag is done in other positions.

These methods are commonly applied for overflow or skimmer slag from the tapping, which usually has a low metal content. This is defined mostly as non-recovery slag. There are, however, other sources of slag which can contain more metal and will be reclaimed. Such materials are slag poured and skimmed off the metal ladle, slag from the metal trap or slag pot, dross from the metal ladle after casting as well as ladle and tapping launder sculls.

These types of slag will often be kept separately from slag which contains little metal, in special slag-pots or slag pits, and are most likely sources to be considered for recirculation or reclamation.

2.4.5 Uses of slag

2.4.5.1 Slag composition and properties

Ferrochromium slags mainly solidify as a mixture of spinel, $MgO \cdot Al_2O_3$ and forsterite, $2MgO \cdot SiO_2$, and will also contain between 3 and 15 % Cr_2O_3, mainly as unreduced or partly reduced ore. The level of Cr_2O_3 will mainly depend on the reducibility of the ore, and to a lesser extent on the process efficiency. This slag is chemically very stable, and has better mechanical properties than many of the rock types used in road-building, paving, landfills etc. Especially in areas where suitable rock for these purposes are in short supply, ferrochrome slag is in great demand. Granulated slag is in addition used as a sand blasting grit, and for the production of refractory castables.

2.4.5.2 Slag processing for metal reclamation

Slag processing to reclaim metal can have two goals: either to produce commercially viable, clean metal or to produce remelt. A combination of the two is common.

In the simplest case only the most metal-rich part of the slag is crushed and returned to the furnace as remelt. Bigger lumps of pure alloy may be picked out as metal to be sold during this process.

To avoid using smelting power to remelt big quantities of slag it is, however, an advantage to remove most of the slag. Moderate crushing, to a maximum size of approximately 30 mm, combined with high intensity magnet separation, is a process suitable for this purpose. This process can also be combined with the picking of clean metal lumps for sale.

If the goal is to recover a maximum of commercially viable metal, a combination of gravimetric processes are usually employed. These processes are all based on the difference in density between slag and metal.

2.4.5.3 Slag processing for sale

The slag processing to make a marketable product will normally be limited to crushing and screening into different fractions for different uses. This can totally or in part be integrated in the metal recovery processing, but is also often a separate process for non recovery slag with low metal content. When the slag is used for bigger landfill purposes, it may not be necessary to do any processing at all.

2.4.6 Metal handling and processing

2.4.6.1 Recovery of cast metal

Recovery of metal cast in beds can be done by using a fork lift or specially made tongs. This will usually be done shortly after solidification. Recovery from layer casting beds is done by front end loader. The fines wall is usually removed some time prior to breaking to accelerate cooling and ease breaking. Sometimes the front end loader must be fitted with a special breaking tool to manage breaking up the bed, since the red hot metal is quite tough. In any case, the metal will be stocked for additional cooling before further processing.

2.4.6.2 Crushing and screening

At least some of the metal cast in beds and moulds will be too coarse for use by customers, and will normally also contain bed or mould protection fines. It must therefore be crushed and screened to the individual customer's size specification, which may vary quite widely, depending on the steel plant's handling and transport equipment.

2.4.6.3 Metal storage and metal shipment

Indoor metal storage is preferred, since dry material is requested by the steel plant in some instances for safety reasons. Outdoor storage may, however, also be used, and if necessary the metal can be covered by tarpaulins. Shipping is normally in bulk: by truck, in containers or by ship.

2.5 Other factors

2.5.1 Accidents

The prevention of accidents and accidental releases is the aim of educational and labour welfare actions. The CO-gas is toxic and forms an explosive mix with air at certain content levels. Its use demands tight pipelines, content measurements in works halls and careful operation. If CO-gas is used as fuel instead of oil, the risks of accidental releases to water are reduced. Possible leaks from hydraulic systems of process equipment are small and can be prevented. Settling pond walls must be firm and controlled.

2.5.2 Process control

A whole modern ferrochromium production process is equipped with automatic control systems, which collect measurements, give needed alarms, adjust and do lockings, calculate and report. However, there are rather few continuous measurements for emissions to air, water and land.

2.5.3 Process operation and maintenance

The ferrochromium production processes are continuous. A high operation time is important for profitable operation, quality assurance and minimising of releases. As high an operation time as possible is a common goal of both production and maintenance. In a modern smelting process an ordinary maintenance stoppage is not held every year. Without this kind of stoppage the yearly operation time is approximately 99 %.

2.6 The Outokumpu process

2.6.1 General

Outokumpu Chrome Oy is a part of the Outokumpu Stainless Steel business area. It produces 600,000 tons of chromite concentrates at the Kemi Mine and 240 000 tonnes of ferrochromium at the Tornio Ferro Chrome Works in Northern Finland.

The chromium ore deposit was discovered close to the town of Kemi in 1959. After detailed geological ore dressing and metallurgical investigations a mine was established in the area in 1968. A plant for processing the ore to ferrochromium followed in the same year. Stainless steel production close by the ferrochromium works started in 1976. The expansion of the Ferro Chrome Works was finished in 1985 and the construction of the Steel Belt Sintering Furnace process in 1989. The number of personnel in Outokumpu Chrome Oy is about 300, of which only 160 are working in the ferrochromium process.

Outokumpu Chrome Oy is certified to ISO 9002 requirements. An environmental system according to ISO 14001 is projected to be certified during 1999. Safety functions are organised as an essential part of normal business operations.

The production flowsheet of Outokumpu Chrome Oy is presented in Figure 1.

2.6.2 Raw material reception and storage

The lump ore is transported by train from the nearby mine. The containers are unloaded either directly into the silos or the material is transported by conveyor to the silos.

The coke is transported by sea, train or truck. The vessels are unloaded and the coke is transported from the harbour by truck to a storage building. The trucks unload the coke directly into the silos. Quartzite is transported by truck and unloaded directly into the silos.

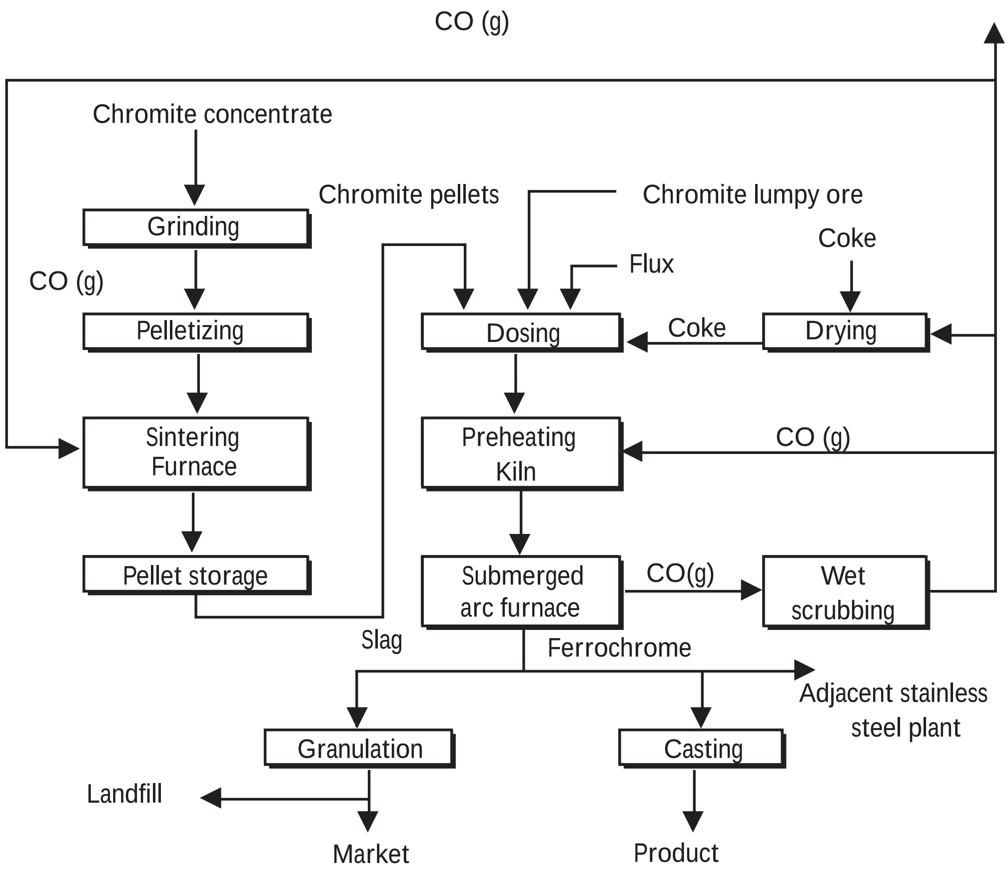

Figure 1. Flowsheet of ferrochromium production.

2.6.3 Pelletising-sintering

At the sintering plant, the concentrate is ground and pelletised and sintered in the Steel Belt Sintering Furnace developed by Outokumpu from an innovation by LKAB of Sweden. The product from the sintering furnace is hard, porous chromite pellets with constant physical and chemical properties suitable for ferrochromium smelting furnaces.

Sintering refers to the heating of pelletised chromite up to a high temperature, at which the chromite grains in pellets are bound together with molten silicates. This forms a strong structure which can withstand mechanical and thermal treatment. In addition to chromite, fine coke and bentonite are used in sintering. Coke is used as the main energy source in the sintering. Bentonite is used as binding agent in pelletising and in the drying stage of the sintering. Bentonite is added as a very fine powder to mix it homogeneously with the chromite.

2.6.3.1 Grinding-filtering

Fine coke, coarse dust and undersize from the product screen are dosed in proportion to the chromite concentrate. The material mix is wetground in a grinding ball mill to a fineness suitable for pelletising and sintering. The suitable grain size is 80 % minus 74 µm. The slurry from the grinding is pumped for filtering.

The ground chromite is separated from the water by a modern capillary filter. The suitable moisture content for pelletising is about 10 %. The separated water is sent back to the mill.

2.6.3.2 Pelletising-sintering

The ground chromite is dosed for pelletising, bentonite and fine dusts are dosed in proportion to the chromite. The materials are well mixed and then pelletised in a rotary pelletising drum to balls of about 12–13 mm diameter. Smaller pellets are recycled to the drum.

The green pellets are fed to the steel belt sintering furnace. The sintering machine is basically a multicompartment oven through which the green pellets are carried on a perforated steel conveyor belt. The green pellets are dried in the drying compartment by circulating gas from the last cooling compartment. In the preheating compartment the temperature of the pellets is increased so that they are calcined and the carbon in the bed is ignited. Heating gas is taken from the second cooling department. In the sintering a sintering temperature of 1,350–1,450 °C is achieved. Heating gas, in addition to the energy from burning of carbon and oxidation of iron, is taken from the first cooling compartment.

The front-end compartments are down-draft, and cooling air to the three cooling compartments is blown from below. To control the temperature profile in the compartments, CO-gas from the smelting or natural gas is burned in the preheating and sintering compartments. Product pellets and circulating pellets are used as bottom layer on the steel belt to protect it from too high temperatures. The exhaust gases are cleaned in cascade scrubbers. Slurries and dusts are recycled back for grinding or pelletising. The bag filter equipment is used for dedusting in different places elsewhere in the process, when needed.

The pellets produced from the sintering machine are screened and the undersize is returned back for grinding. Part of the product is recycled back to the bottom layer. The main product is transported directly to the dosing silos of the smelter or to the indoor storage room to await further transportation. 10–20 kg/tonne pellets are recycled in the process.

2.6.4 Coke drying

The moisture of the coke used in the smelting process can be as high as 10–20 % when the coke is wet quenched. Coke drying is a way of ensuring the right amount of carbon in a smelting charge. The drying is done in a shaft furnace, to a moisture level of 1 % using furnace CO-gas as fuel.

2.6.4.1 Shaft furnace

Coke is lifted by belt conveyors to a feed bin and then fed into the furnace by vibrating feeders and feed chutes. The furnace has two shafts, and is heated by burning CO gas from the smelting furnaces in a separate combustion chamber. The combustion gas is diluted by air to obtain a proper temperature before the inlet to the coke bed at different levels inside the furnace. The coke falls down on the drying cone planes and the heating gas flows through the coke bed. The dried coke is screened, as it is beneficial to keep the content of fines in the smelting process as low as possible. The undersize coke and the filter dust are used as fuel in the sintering process. The oversize is a reductant to the smelting charge. The discharge and transport devices after the furnace are provided with dedusting equipment.

The off-gas from the drying process is cleaned in a bag filter by maintaining a gas temperature of over 100 °C.

2.6.5 Weighing and feed control system

The lump ore is transported by train from the mine nearby. The containers are unloaded either directly into the silos or the material is transported by conveyor to the silos. The pellets have their own store house, and are mostly transported directly to the dosing bins of the smelter.

2.6.6 High carbon ferrochromium production

The raw materials for the reduction and smelting of chromites are upgraded lumpy ore and hardened pellets. Coke is used as a reductant and quartzite as a slag additive. The charge is preheated and dosed into the smelting furnace.

2.6.6.1 Preheating

In the Outokumpu process the charge is preheated by the CO gas generated in smelting, in a static preheating equipment of shaft type. Through preheating the charge, it has been possible to cut the consumption of electric energy by 70–90 kWh per a 100 °C increase in preheating temperature and 1,800–2,500 MJ (0.5–0.7 MWh) /tonne FeCr. At the same time the ferrochromium production increases by 20 %, if a preheating temperature of 700 °C is used.

By preheating the charge at 700 °C, moisture and a major part of the volatiles can be removed before the material is charged into the electric furnace. Thus the formation of reduction gases in the submerged arc furnace is stable.

Raw materials are dosed in the existing system as charge batches. The batches are lifted to the feed bin or directly into the preheating kiln by the existing belt conveyors or ship hoist. If there is a feed bin, material is fed by a vibrating feeder and feed chute into the kiln.

Heating gas is produced by burning CO-gas in a separate combustion chamber. The combustion gas in the chamber is cooled using off-gas from the venturi scrubber to gain a proper temperature and to avoid oxygen. The gas temperature to the charge material is controlled finally in the mixing chamber by the recycling gas flow from the scrubber. The excess gas from the venturi scrubber is released to the atmosphere. A shaft type preheater is above the smelting furnace. There are charging tubes between the preheating kiln and the submerged arc furnace.

2.6.6.2 Smelting

Ferrochromium is produced in two closed submerged arc furnaces with transformer capacities of 40 and 75 MVA.

The submerged arc furnaces include three-phase A.C. operations with three Söderberg electrodes and energy generation by electric resistance heating. Close control of the charge composition and its sizing, and of the slag composition are essential for effective operation of the submerged arc furnace.

The totally closed electric furnace is covered by a water-cooled refractory roof. The smelting charge flows continuously from the tubes to the hearth so that the material in the tubes at the same time forms a gas tight seal. Chromite is reduced both in solid and liquid state. Smelted products go on to the bottom of the furnace.

The smelting process produces metal and slag, and CO-rich off-gas. Products are tapped at intervals of 2–4 hours after a fixed quantity of input electricity. The produced metal is of charge chrome with a chrome content of 50–55 %, carbon 7 % and silicon 3–5 %. The slag consists mainly of SiO_2, Al_2O_3 and MgO in different phases but also smaller amounts of CaO, chromium and iron oxides and metal fragments. The chrome content in slag is 7–8 %, in oxide and metal form.

The solid products obtained from smelting ferrochromium are metal, slag and dust. The dust is scrubbed in a venturi system and is produced as a slurry.

CO gas

The reduction develops 650–750 Nm^3/tonne FeCr of CO-gas with a reaction energy of 7,550–8,300 MJ (2,100–2,300 kWh) with good furnace sealing.

The CO-gas formed during reduction is sucked out from the closed furnace through two take-offs to wetting scrubbers. In normal operation, both scrubbers operate at the same time, but the furnace can operate with one scrubber alone at full furnace power. At Tornio, high pressure scrubbers are used. The possible extra CO gas is ducted out to the CO-gas stack and burned there.

The CO gas is transferred by means of pipelines in the plant area as easily as any fuel gas. The CO gas is utilised as fuel. It can be used by direct burning in the integrated ferrochromium and stainless steel production.

Treatment of process waters

Water from the gas scrubbers will contain different quantities of suspended solids. These must be removed before the water is recirculated or discharged.

The contaminated water is pumped to a combination of thickeners and settling ponds. Since the particles are mostly extremely fine, it is necessary to add a flocculant to assist settling in thickeners.

The water will also contain cyanides. This cyanide level can be reduced by using the scrubber water for slag granulation, which leads to evaporation and oxidation of most of the cyanides. Further reduction can be achieved by long retention times in large ponds, allowing time for oxidation of the cyanides before discharge, and also allowing time for settling suspended solids to a low level. Cyanide removal utilises the heat content of slag.

2.6.7 Post furnace operations

2.6.7.1 Tapping arrangements and tapping equipment

Tapping is done when a fixed quantity of MWh is achieved since the last tapping. The ferrochrome furnaces have one or two tapholes, i.e. a specially designed refractory inset in the furnace side-wall with a circular opening, which will be plugged with refractory clay between each tap. Slag and metal are tapped through the same taphole. If the furnace has more than one taphole, one can be used, while the others are under repair or are in stand-by for use. A tapping launder channels the tapped metal and slag to two common ladles. Lower density slag will float at the top. The overflow through the second ladle goes to the granulating basin.

The taphole is opened using a pneumatic drill. Oxygen lancing is also used for taphole opening as a back-up or complement to drilling. Oxygen lancing involves passing oxygen through a steel tube.

During tapping, the taphole may be blocked by pieces of unreacted raw materials, broken electrode pieces, or by freezing of metal and slag. A tapping gun is used to remove blockages.

The furnace is closed using a mud-gun, which is mounted on overhead rails. The gun consists of a chamber for the refractory clay, which is emptied by a piston through the mud-gun barrel into the taphole.

The metal vessel used is a ladle with welded steel shell with an inside lining of refractory materials. The metal is cast from the ladle after the tapping is finished. The transportable tapping vessels can be brought to the tapping positions by overhead crane and ladle car.

In the granulation process, slag goes via a launder to a water basin, where the slag flow is broken up into droplets and quenched by high pressure water jets.

2.6.7.2 Secondary slag/metal separation

The practice for secondary slag removal is the use of a slag skimming machine. If the slag layer on top of the metal is thick, some slag will be poured off prior to skimming.

2.6.7.3 Use of molten ferrochrome in stainless steel production

The liquid metal can be used directly in steel production. This has the advantage that later steps in the alloy production can be minimised, and also that the heat content of the liquid metal, corresponding to 1,450–1,600 MJ (400–450 kWh) per tonne of alloy, can be utilised. Some ferrochrome is added to the steel in solid form.

The metal is poured into beds made up of a bedding material and left there to solidify. After solidification the solid cakes of alloy are removed, and the bed is made ready for pouring again.

The bedding material is metal recovered from slag of 0–25 mm or ferrochrome fines, which is generated during crushing and screening of the alloy. Ferrochrome has the advantage that it does not contaminate the alloy, and some of the bed materials also melt during pouring, and are thus “recirculated” without use of additional energy.

2.6.7.4 Slag handling methods

The slag flow goes to a granulation basin, where water jets break up the slag flow into small fragments and quench the slag. Because relatively shallow basins are used, they can be emptied by front end loader. Slag granulation will contribute to reduce emissions of fumes and dust.

2.6.7.5 Uses of slag

Ferrochrome slag is chemically very stable and is used as construction material in house and road building, landfills and for the production of refractory cast tables.

In order to recover a maximum of marketable metal, a combination of gravimetric processes is employed in the slag processing. Heavy media separation and spiral washing are used. Recovered metal is used as casting bed material.

2.6.7.6 Metal handling and processing

Recovery from layer casting beds is done by front end loader. The metal has to be stocked for additional cooling before further processing.

The metal cast in beds must be crushed and screened to the individual customer's size specification, which may vary quite widely, depending on the steel plant's handling and transport equipment. Crushing is performed using two jaw crushers.

The crushing and screening plant also consists of a number of screens of various screen sizes. Transport between the processing units and from processing to the metal storage is by belt conveyor.

The metal is stored indoors since dry material is requested by the steel plant. Shipping is in bulk. Loading from the storage is done by front end loader.

3 Present Consumption/ Emission Levels

The main environmental issues in high carbon ferrochromium production are air and water pollution and energy consumption. Wastes without economic utility come mainly from the scrubbing of submerged arc furnace off-gases. The following will describe the consumption and emission levels in Finnish ferrochromium production.

3.1 Present consumption levels

3.1.1 Raw materials and energy consumption

In the pelletising and sintering process the additional materials to chromite are binding and energy source agents. The amount of bentonite needed for binding is 0.5–0.8 %. Respectively 1.5–2.0 % fine coke is used. The proportion of CO-gas from smelting as external energy is 20–40 %.

Due to the highly efficient use of cooling gases at the front-end compartments and low exhaust gas temperatures, the external energy consumption in the steel belt sintering furnace is low compared to shaft or grate sintering furnaces. The external energy, 700 MJ (200 kWh) /tonne pellets, comes from burning carbon and CO or natural gas.

The external energy for drying the coke in the shaft furnace process comes from burning CO gas generated in the smelter. The energy requirement is 550–700 MJ (150–200 kWh)/tonne coke. The undersize from the screening and separated dust amount is less than 5 %.

The following consumptions per tonne of ferrochromium are achieved in the smelting phase with the use of pellets and preheated charge and no remelts:

- Chromite 2,300–2,400 kg
- Reductants 500–550 kg
- Electricity 11,150–12,600 MJ (3,100–3,500 kWh)
- Fluxes 200–300 kg.

The previously mentioned electricity and reductant consumptions are for the whole production process. The electrical energy consumption for smelting is about 95 % of total consumption. The main part of the remaining 5 % is electrical energy needed for the off-gas treatments. The chromium recovery is from 80 to 85 %.

Water is needed both as process water and cooling water. Process water is used for gas scrubbing and slag granulation. If the process water treatment is closed, the usage is typically 5–15 m^3/ton FeCr. The need for cooling water is at the same level. The cooling water circuits are closed or open. The electrode paste consumption, 7–9 kg/tonne FeCr , depend on the raw materials used.

3.1.2 Energy recovery

A volume of 650-750 Nm^3 CO-gas is developed in the reduction of one tonne of FeCr with a reaction energy of 7,550–8,300 MJ (2,100–2,300 kWh).

The CO-gas formed during reduction is sucked out from the closed furnace through two take-offs to wetting scrubbers. At Tornio high pressure scrubbers are used. The CO-gas is transferred by means of pipelines in the plant area as easily as any fuel gas. The CO-gas is utilised as fuel. It is used by direct burning in the integrated ferrochrome and stainless steel production.

3.2 Environmental emissions

3.2.1 Emissions to air

3.2.1.1Raw materials handling and storage

The dosing stations of the ferrochrome smelting charges are equipped with dedusting devices. For the cleaning operations bag filters are used. The dust emissions to air from the smelting charge materials are 10–20 g per tonne of ferrochromium.

Fugitive dust emissions to air are decreased by indoor storage and storing directly in silos.

3.2.1.2 Pre-processing

Pelletising-sintering

The steel belt sintering furnace is closed. The pressure is kept at the zero level or less inside the furnace to avoid leakage of gas to the environment. The off-gas amount to air is 2,500–3,000 Nm^3/tonne pellets including 80–120 kg CO_2. The process off-gases are cleaned by low pressure wet scrubbing and the dedusting from other places in the process is performed by bag filters, the dust emission to air is 10–20 g/tonne pellets.

The conditions in the sintering furnace are oxidising. Burning of coke generates 0.2–0.3 kg SO_2/tonne pellets. Correspondingly NO_2-emissions in firing are 0.3–0.7 kg/tonne pellets.

Coke drying

The off-gas from the shaft kiln for coke drying is cleaned by a bag filter. After this the gas flows to the atmosphere. The coke dust emission to air is 35–45 g/tonne coke. The temperatures of the coke bed are low for the formation of SO_2. Emissions of CO_2 amount to 45 to 70 kg/tonne FeCr and of NO_2 correspondingly about 20 g.

Weighing and feed control system

The dosing stations of the ferrochromium smelting charges have been equipped with dedusting devices. Bag filters are used for cleaning. The dust emissions to air from the smelting charge materials are 10–20 g/tonne FeCr.

3.2.1.3 Core processes

Water from the slag granulation is collected and recirculated in the water treatment system.

Preheating

The preheating kiln is closed. The pressure is kept at the zero level over the bed in the shaft type kiln to avoid leakage of air into the kiln or leakage of gas to the environment. Carbon losses are minimised by the temperature of 800 °C and very low oxygen content inside the kiln. The off-gas from the kiln is cleaned in a venturi scrubber. The sludge is stored after settling. The emissions to air depend on the raw materials used and preheating temperature. In the shaft type kiln where pellets/lumpy ore mix and a preheating temperature of 700 °C are used, the off-gas amount to air is 500–600 Nm^3, CO_2-amount 300–400 kg and dust emission 1–5 g per tonne of FeCr.

Smelting

The conditions in the closed smelting furnaces are reducing for the formation of NOx or chromium trioxide, but are favourable for cyanide and PAH development. The Cr (VI) content of furnace dusts is 5–100 ppm in the closed furnace. The furnace dust contains mainly SiO_2, MgO, Zn and C, and smaller amounts of Cr, Fe, Al_2O_3 and CaO.

The raw materials contain some amount of nitrogen and alkalis, which stabilise gaseous cyanide species. The cyanide level in the gas is mainly controlled by nitrogen and alkali contents of the charge. The gaseous cyanides level in the smelting furnace is typically 20–50 g/tonne FeCr. In the closed furnace a substantial amount of these cyanides are transferred into the venturi scrubber water.

The CO-rich gas, formed in the closed smelting furnace, contains 85–90 % CO, 5–7 % H_2, 2–5 % CO_2, 2–5 % N_2 and 1–2 % H_2O. Its dust amount varies strongly. After cleaning in venturi scrubbers, the dust amount is 20–100 g/tonne FeCr. The CO gas is a high quality fuel with a very low sulphur content. Because the off-gas volume from smelting is small and utilised in other processes, dust emissions into the atmosphere are minimised. The gas goes to different consumption places, where other fuels, for instance heavy oil and liquefied petroleum gases are substituted. The decrease in fuel oil consumption means reduction of sulphur dioxide emissions to air.

3.2.1.4 Post furnace operations

Metal Processing

Any handling of warm and dry metal will cause dust emissions. Dust from crushing and screening, which is nearly pure metal, is collected and cleaned in bag filters. Ferrochromium dust is packed in barrels and then used in the stainless steel production.

The formation of dust depends greatly on the composition of the produced metal. After filtering the dust emission to air is 20–50 g per tonne of ferrochromium.

Handling, transport and shipment will generate some dust in the ambient air, which is not cleaned.

3.2.2 Legislation and regulation in Finland

Finland has no single environmental law at the moment. The environmental legislation is composed of a number of individual acts. A new Environmental Protection Act is currently under preparation and will combine the environmental acts according to the requirements of the Council Directive 96/61 /EC of September 1996 concerning integrated pollution prevention and control (IPPC).

Presently, the integrated approach is included in the two separate permit procedures: the environmental permit procedure according to the Environmental Permit Procedure Act (735/1991) and Decree (772/1992) and the water discharge permit procedure according to the Water Act (264/1961) and Decree (282/1962).

The Environmental Permit Procedures Act combines the permit procedures of the Air Pollution Control Act and Decree, the Waste Act and Decree, the Health Protection Act and Decree and the Adjoining Properties Act. The competent authority in environmental permit matters is, depending on the line of activities, either the Regional Environment Centre or the local environmental board.

When discharging waste waters, the Regional Environment Centre must be notified in advance regarding any plans for the discharge of wastewater in the cases listed in the Prior Notification Decree. The Centre assesses the notification and judges whether the activity will cause water pollution. If the pollution is unavoidable, the polluter must apply for a permit from the Water Court or from the local environmental board. Substantial polluters send their applications directly to the Water Court. Polluting of groundwater is totally forbidden; this means that no permit can be granted for discharging pollutants into the groundwater.

In the metallurgical industry, an environmental permit granted by the Regional Environment Centre and a water discharge permit granted by the Water Court are needed.

Although the environmental legislation is based on a sectoral approach, the permit system in each sector follows certain uniform lines including the following elements (both in environmental and water permit matters):

- An application describing the activity and its environmental effects is to be submitted to the competent authority. The data and information that the operator of an industrial plant (the applicant) has to submit in the form of an application to the authority is described in the above mentioned Acts and Decrees.
- The documents are public and the persons and organisations affected by the project have a right to comment on them.
- The competent authority makes a decision including emission limits and other permit conditions.
- Those concerned have a right to appeal against the decision.
- A revision of the decisions and permit conditions is made by a certain deadline stipulated in the permit (3–10 years when wastewater discharges are concerned) or when there are significant changes in operation or emissions or when unexpected effects are detected.

Right at the preliminary stage of planning a new establishment, the necessary permits and environmental aspects are to be surveyed. The enterprise is expected to recognise that the environmental criteria may affect siting as well as other economic and technical decisions. Even in the case of changing the production, raw materials or technical devices at an existing plant, the authorities must be informed as soon as these decisions are made, and negotiations shall be initiated to survey the possible need for renewing the permits.

The legislation is based on the Polluter Pays Principle in the sense that the polluter pays all pollution abatement costs, which also include the monitoring costs. In addition, polluters of watercourses are obliged to pay indemnities to the owners of water and shore areas as well as to professional fishermen for any damage caused. A typical feature of the permit procedure is the case-by-case consideration of applications and tailor-making of the permit conditions. The permit conditions are expressed as emission limits and compulsory measures and not as technical standards.

3.2.3 Emissions to air at Outokumpu Chrome Oy

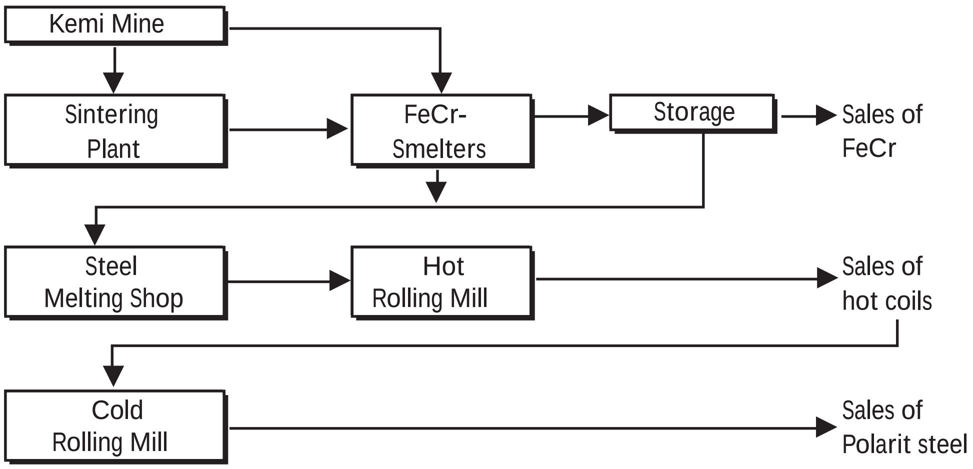

Figure 2. Integration of Kemi Mine and Tornio Works, which include both ferrochromium and stainless steel production.

The air emissions allowed for the integrated Tornio works and ferrochromium works (see Figure 2) contain the following regulations for the ferrochromium plant:

1. the dust concentration of the exhaust gases from the drying of coke must not exceed 50 mg/m³.
2. the dust emission from the whole sintering process must not exceed 40 t/a.

These regulations were obeyed in 1997, dust emission from coke drying was 3.9 tonnes and from the sintering process 4.7 tonnes.

The ranges of emissions to air in the ferrochromium industry are presented in Table 4.

Table 4. Emissions to air at Outokumpu Chrome Oy.

Process stage	Dust	CO_2	NO_2	SO_2
Raw material dosing	10–20 g/t FeCr			
Pelletizing-sintering	10–20 g/t pell.	80–120 kg/t pell.	300–700 g/t pell.	200–300 g/t pell.
Coke drying	15–25 g/t FeCr	30–70 kg/t FeCr	20–30 g/t FeCr	
Preheating	1–5 g/t FeCr	300–400 kg/t FeCr	20–40 g/t FeCr	
Smelting	10–20 g/t FeCr	30–60 kg/t FeCr		
Product handling	20–50 g/t FeCr			
Total	80–120 g/tFeCr	600–700 kg/t FeCr	500–1,200 g/t FeCr	300–500 g/t FeCr

The production of ferrochromium was 236,650 tonnes in 1997. The emissions in the same year were:

- Dust 24.2 t 102 g/t FeCr
- NO_2 87.1 t 368 g/t FeCr
- SO_2 92.4 t 390 g/t FeCr
- CO_2 152,222 t 643 kg/t FeCr

3.2.3.1 Off-gas monitoring

The emissions from the ferrochromium plant were measured from all stacks in 1997 according to the monitoring program. The CO_2 emissions are calculated from the carbon contents of the raw materials and fuels used. The SO_2 emission comes from the chromite concentrate and fine coke used in the sintering process, and it is calculated from the materials balances.

The Metallurgical Laboratory of Outokumpu Polarit Oy performs the air emission measurements according to the measurement program defined by the authorities. The laboratory has a certified quality system according to SFS-ISO 9002. The quality system also fulfils the requirements of the EN 45001 standard.

In emission measurements, the mass flows, temperatures, moistures, compositions and particulate matter are determined. The chemical composition of the particulate matter is often also analysed. The results are reported to the personnel and to the authorities.

3.2.4 Emissions to water

The permit conditions for Tornio works are according to the Finnish-Swedish boundary river commission as follows. The process waters must be cleaned in such a way that the effluents coming from the integrated Tornio works (ferrochromium and stainless steel production) do not contain as quarterly means more than:

- suspended solids 300 kg/d
- total nitrogen 460 kg/d
- total chromium 7 kg/d
- dissolved chromium 3 kg/d
- total nickel 5 kg/d
- total zinc 5 kg/d
- cyanide 5 kg/d
- oil 2 kg/d

The proportion of the ferrochromium production is significant in the discharge of suspended solids, total chromium, total zinc and cyanide.

3.2.4.1 Waste water monitoring

The waste water analyses are done once a week according to a measuring program prearranged with the authorities. The samples are taken both from the process water and cooling water drains. The water flow, solids content, temperature, conductivity and pH are first measured. Chromium, iron, zinc and nickel are analysed both in the total and dissolved form. The total nitrogen, fluorine, cyanide and oil concentrations are analysed, too.

The Metallurgical Laboratory of Outokumpu Polarit Oy performs the waste water monitoring. The laboratory has a certified quality system according to SFS-ISO 9002. The quality system also fulfills the requirements of the EN 45001 standard. The results are reported to the personnel of the plant and to the authorities.

3.2.4.2 Effluents in 1997

The total emissions to the waterbody from the ferrochromium production for 1997 are shown in Table 5.

In Tornio there is in use a thickener, slag granulation and settling ponds for water treatment. The suspended solids amount in the bleed after the treatment was 75–150 g/tonne of ferrochromium. The emissions of total Cr were about 3–5 g, of total zinc 3–7 g and of cyanide 0.3–1.5 g per tonne of ferrochromium produced. The cyanide emission depends on the temperature outdoors.

Table 5. Actual emissions at the Outokumpu Chrome works in 1997.

	kg/d	t/a
Suspended solids	85	31
Total chromium	2.5	0.9
Total zinc	3.1	1.1
Cyanide	0.6	0.2

3.2.5 Solid waste management

Wastes without economic utility come mainly from the off-gas dusts of the submerged arc furnaces. These solids, 30–40 kg/tonne FeCr, are transported to a depository. The composition of the dust or sludge varies depending on the smelting charge materials and processes:

- Cr_{tot} 1–10 %
- Fe_{tot} 1–6 %
- C 3–10 %
- MgO 20–40 %
- SiO_2 15–30 %
- Al_2O_3 1–10 %
- CaO 0–5 %
- S 0.5–2 %
- Zn 1–10 %
- Na_2O 2–4 %
- K_2O 2–5 %

The amount of solid wastes transported to the depository was 8,000 tonnes in 1997.

3.2.6 Noise

The heavy machinery and large fans used in the ferrochromium production can give rise to emissions of noise or vibration. The mechanical scull releasing from ladles is also a noise source. The loading and unloading of trucks as well as the road transport create noise, too.

3.2.7 Environmental management

Internally an environmental management system means that the environmental viewpoint shall be taken into consideration in all fields of operation: production, maintenance, planning, research etc. The development of environmental management aims at concrete improvements in environmental actions.

The entire staff participates in fulfilling the environmental management system. Each person must take responsibility for the environment. In accordance with environmental policy, work is performed in a responsible manner, without harming the environment, wasting energy or resources.

Candidate Best Available Techniques

4

The production of ferrochromium is an energy-intensive process. The total electricity consumption is 9,300–16,200 MJ and reductant consumptions without prereduction 500–700 kg per tonne of ferrochromium in different processes. All methods to minimise the specific energy consumptions have considerable impact on both production costs and environmental aspects. The reduction process is a typical high-temperature process in which the most economical and environmentally sound unit size is the largest possible in practice. The production and energy consumption depend basically on the quality of raw materials.

Chromium recovery in the process is one factor which affects both energy and raw material consumptions. Recovery can be improved by pretreatment methods. Profitable operation and minimisation of emissions demand as high operation time as possible. The highest possible process equipment capacity and operation time are the base for a high labour productivity. The process outputs contain a lot of energy. These energies must be utilised as effectively as possible.

The whole modern ferrochromium production processes are equipped with automatic computerised control systems, which intensify process control and improve process knowhow.

Because of the raw material and energy consumptions, production, emissions and operation time, the ferrochromium process at Outokumpu Chrome is considered to be an individual total candidate. Automation is based on computerised process control systems and separate control instruments with programmable logic. The certified quality assurance system is in compliance with ISO 9002 standard. The goal will be to certify the environmental management system to ISO 14001 standard during the future months.

4.1 Raw materials handling and storage

Raw materials are preferably stored on hard surfaces to prevent contamination, using indoor or outdoor storages. Material sampling is necessary to identify raw material qualities.

The environmental issue in raw materials handling and storage is the emission of dust to air. Excessive dusting is prevented by water spraying of dry fine grained materials. Fugitive dust emissions to air are decreased by storing inside warehouses and storing directly into silos. Storage and reclamation systems are suitable alternatives for dusty materials. Sealed vehicles, conveyors and transfer systems should be used. Handling times and dropping of materials must be minimised to avoid crushing.

Robust extraction and filtration equipment should be used on dusting delivery points, silos, pneumatic transfer systems and conveyor transfer points. For cleaning, operations bag filters are used. Pressure drop should be monitored to control the cleaning mechanism.

The collected dusts from the processes which are exploitable are recycled, and used in the agglomeration processes.

4.2 Pre-processing

The fine ore cannot be fed directly into the submerged furnace without causing operation problems and must therefore be agglomerated before charging to the smelting furnace. The pretreatment methods extend the ferrochromium process and increase investment costs, but they reduce smelting costs. The materials should flow directly into the following process if possible to minimise handling.

4.2.1 Agglomeration

The agglomeration processes in use are pelletising-sintering, sintering of fine ores and briquetting. Because of fine materials, dust emissions to air are prevented by extraction and abatement equipment. Enclosed conveying systems should be used for dry materials. Accurate weighing equipment and control systems are needed to dose right qualities of different materials.

Wet grinding, filtering, and pelletising systems are all suitable to prevent dusting. Water is recycled. Ground chromite has a large specific surface area owing to fine chromite particles and very small pores in structure. The reduction rate of this material is high later in the core processes, which improves chromium recovery.

The quality of sintered pellets is homogenous because of the use of concentrates and the ground porous structure. The steel belt and shaft furnaces are used to sinter chromite pellets.

The external energy consumption in the steel belt sintering furnace is low compared to the shaft furnace. The need, 700–1,400 MJ per tonne pellets, comes from burning carbon, CO-gas from the smelting furnace or natural gas. The energy consumption depends on the characteristics of different chromite concentrates. The sintered pellets are screened and transported either directly to the smelting dosing system or to storage. An indoor storehouse is preferable.

The steel belt sintering furnace is closed. The emissions from the process are dust, CO_2, NO_2 and SO_2. The off-gases should be cleaned by low pressure wet scrubbing and dedusting from the other points in the process, performed by bag filters. Burning fuels generates CO_2 and NO_2. The use of coke also develops SO_2. The operation of the process is controlled by computerised control systems.

Sintering in a grate furnace demands more energy compared with the steel belt furnace process. The consequence is higher emissions of CO_2 and SO_2. The fuel is coke breeze. The subsequent crushing, screening and transport of sinter will lead to dust formation.

Briquetting does not need high temperatures and thus any fuels. It does not develop CO_2 and SO_2 emissions. The investment costs are lower than for sintering and pelletising-sintering. The chromite particle size is coarser than ground chromite in pellets. This decreases chromium recovery in smelting compared with sintered pellets. The compressive strength is lower, which leads to fines formation later in the ferrochromium production process. Dust emissions to air are prevented by local filter installations in silos and at various loading and unloading points.

The Outokumpu Chrome process consists of wet grinding, blending, pelletising and sintering in the steel belt furnace. The off-gases are washed with the low pressure cascade scrubbers. The energy consumption from carbon and CO-gas is 750 MJ per tonne of pellets.

4.2.2 Coke drying

Coke drying is a way to ensure the right reductant quantity in the smelting charge. The reductant may contain different amounts of moisture and, in a cold climate, snow or ice. Shaft and rotary furnaces are used. The shaft furnace generates less dust and fines. Its specific energy consumption, 550–700 MJ per tonne of coke, is lower. Subsequent screening and transport also generate dust. The CO-gas from the smelting furnace is used as a fuel. The burning generates CO_2 and NO_2. The process should be provided with extraction and abatement equipment. Bag filters and wet scrubbing are used.

Outokumpu Chrome uses a shaft furnace for coke drying. The off-gases are cleaned on a bag filter. The energy consumption from CO-gas is 550–700 MJ.

4.3 Core processes

Accurate weighing equipment and control systems are needed to dose correct quantities of smelting charge materials. Fugitive dust emissions to air are decreased by in-house storage. Dosing processes are provided with extraction and abatement equipment. Bag filters are used.

Outokumpu Chrome has inside storage for pellets and coke. The upgraded lumpy ore is transported by train from Outokumpu's own mine and is fed directly into the dosing silos. The flux is quartzite and it goes from the cars into the silos. Bag filter systems are used for dedusting.

4.3.1 Preheating

The preheating of charge materials cuts the specific electricity consumption by 250–330 MJ per 100 °C increase in preheating temperature in smelting. At the same time, the ferrochromium production increases. Shaft-type and rotary kilns are used. In the shaft-type kiln crushing up of charge material and dusting are lower. The utilisation of fuel energy is higher and less maintenance work is needed.

The kiln processes are equipped with extraction and abatement equipment. Because of the temperatures, wet scrubbing is suitable to clean off-gases. The sludge can be recycled. The CO-gas from the smelting furnace is used as a fuel. The emissions to air are dust, CO_2 and NO_2. They are lower in the shaft-type kiln than in the rotary kiln. High operation time is essential for the smelting furnace.

The preheating in the Outokumpu Chrome process is performed in a shaft-type kiln. The off-gas is cleaned in the high pressure venturi scrubber. The yearly operation time of the kiln, excluding the maintenance stoppage every three years, is 97–99 %.

4.3.2 Prereduction

The rotary kilns are used for the prereduction of chromite. Prereduction can decrease the specific electricity consumption in smelting more than preheating can. In practice, the weaknesses are an accretion formation, variations of prereduction degrees, operation times and costs, heat losses and utilisation of energy /7/. The heat energy left can be used in the waste boiler to generate steam.

The rotary kilns produce rather high dust contents in off-gases. If a coal with higher sulphur content is used it increases SO_2-emissions. The high temperatures increase fuel consumptions and CO_2-emissions to air.

4.3.3 Smelting

Transfer distances after preheating or prereduction to smelting should be as short as possible to avoid heat losses.

The smelting furnaces are closed, semiclosed or open. The material and electricity consumptions depend on the quality of ores used. The conventional open submerged arc furnace process using lumpy ores and fines without any agglomeration consumes 2,400–3,000 kg of raw materials, 550–700 kg of reductants and totally 13,700–16,200 MJ of electricity per tonne ferrochromium. With the use of pellets and preheated charge, the corresponding consumptions without remelts are 2,300–2,400 kg, 500–550 kg and 11,150–12,600 MJ. If the prereduced pellets charge is used, an electricity consumption 9,350–11,150 MJ has been reached with the reductants amount of 600 kg per tonne ferrochromium. The weakness is the operation of the prereduction rotary kiln. Without the prereduction process the electricity consumption of the D.C. plasma furnace is close to 16,200 MJ per tonne of ferrochromium. The best recoveries are reached by agglomerated chromites from fine materials.

Only closed smelting furnaces and furnaces with closable hoods offer favourable possibilities for the reaction energy utilisation of carbon monoxide gas which is generated by the reduction reactions. The CO-gas is a high quality fuel with a very low sulphur content. The energy is 7,550–8,300 MJ per tonne of FeCr.

CO-gas can be used as a fuel for many purposes or to produce superheated steam or other energy. The best utilisation is achieved in direct burning replacing other fuels, e.g. heavy oil. In ferrochromium production, CO-gas is used in coke drying, sintering, preheating and heating of ladles. In the integrated works, CO-gas is also used in the stainless steel production.

The CO-gas volume is the smallest from closed furnaces with good furnace sealing. The closed furnaces must be equipped with pressure control inside the furnace and pressure raise for the consumption points. The CO-gas from the closed furnace must be washed in high pressure venturi scrubbers because of high temperatures. The operation is monitored by continuous gas pressure, water pressure and volume amounts. In the semiclosed and open furnace processes bag filters can be used. The emissions to air are dust and CO_2 after burning of CO. Cr (VI) is very small from closed furnaces. The dust composition from the bag filters or settled sludge from the scrubbers is unsuitable for recycling. In the closed furnace process, gaseous cyanides from the furnace dissolve completely into the scrubbing water.

A raw gas stack directly out without washing from the smelting furnace should only be used in rare exceptional cases.

Process water is used for gas scrubbing and slag granulation. The process water treatment should be as closed as possible.

Outokumpu Chrome uses preheated smelting charge. The raw materials are mainly pellets and minor upgraded lumpy ore. The two submerged arc furnaces are closed. The consumption of raw materials is 2,300–2,400 kg, coke 500–550 kg and of electricity 11,500–12,300 MJ per tonne of ferrochromium. The chromium recovery is 80–85 %. The CO-gas is washed in the high pressure venturi scrubbers. The furnace capacities are high. Maintenance stoppages are every three years. Otherwise, the yearly operation times are 99 %. The CO-gas is used as a fuel in about half of the different processes of the ferrochromium production and the adjacent stainless steel production. The CO-gas replaces heavy oil and petroleum gas.

4.4 Post furnace operations

4.4.1 Tapping

The taphole of the smelting furnace is normally opened using a pneumatic or hydraulic drill. Oxygen lancing is also used, either as the only method or as a back-up or complement to drilling. A tapping gun helps to remove blockages. The tap-hole is closed using a mud gun.

The most frequently used arrangement for ferrochromium is cascade tapping. Metal and slag are tapped together into the same vessel(s).

Hoods and ducts should be used to collect fumes and smoke from tapping. The cleaning equipment which is most frequently used is the bag filter. A cyclone or other low efficiency dust catcher may be necessary to prevent sparks entering the filter. Wet scrubbing can also be used. The collected dust or settled sludge must be deposited. This volume is very small.

Outokumpu Chrome uses pneumatic drills and if necessary oxygen lancing and tapping guns. The tapholes are closed by mud guns. Cascade tapping is used.

4.4.2 Metal and slag handling

The normal practice for slag removal is first pouring and then use of a slag skimming machine.

If possible, molten ferrochromium is used directly in the adjacent stainless steel melting shop. The bed casting and layer casting are the most frequent methods of casting ferrochromium because of the simplicity and low cost of the methods. The granulation of ferrochromium does not cause dusting. The strength or size of granules may not satisfy all customers.

In the granulation process, slag is quenched by high pressure water jets. If slag- pots or transportable troughs are used, the slag is normally transported in liquid form by vehicle to a slag teeming station and is allowed to cool there before it is broken up. Slag granulation and water spraying of slag in a pit or at a teeming station will contribute to reducing emissions of fumes and dust.

During the ladle or slag-pot transfer from one position and operation to another, fume collection is difficult and even impossible. This will be also the case for the bed and layer casting and teeming of the slag-pots.

All handling of dry metal and slag should be minimised. The product handling process for ferrochromium should be equipped with robust extraction and filtration equipment. Bag filter technology is suitable for dedusting.

Ferrochromium dust is used directly in the stainless steel production or is remelted after agglomeration. Indoor and outdoor storages are used, with indoor metal storage preferred.

In the Outokumpu Chrome ferrochromium process, slag removal from the casting ladle is performed by pouring and the skimming machine. Half of the molten ferrochromium is transferred directly to the adjacent stainless steel melting shop. The metal which is cast is poured in beds made up of metal recovered from slag. Slag granulation is used. A bag filter is used for dedusting in the product handling process. The ferrochromium dust is packed in barrels and used in stainless steel production. The metal is stocked in the indoor storage before being transported to customers.

4.4.3 Slag processing for metal reclamation

The product of slag processing to reclaim metal is either marketable or a remelt. Because the goal is to achieve maximum metal recovery, lumpy slag and slag tailings are crushed or milled to liberate small droplets of contained metal. The gravimetric processes, heavy media separation and jig washing for coarser fractions, spiral washing and washing tables for fine grained materials, are used to recover an optimal amount of marketable material. Due to dust losses in handling and in the ferrochromium consuming processes, lumpy alloy is preferred. Recovered fines are used as casting bed material or are returned as remelt.

All handling and processing of dry slag will result in dust emissions. The handling steps and processing units can be closed and also connected to filters or other types of emission control equipment. Water spraying should be used to avoid dust formation in open handling. For wet gravimetric separation units, water will be reused after settling in ponds or thickeners. The slag is chemically very stable and can be stored in slag dumps or depositories.

The lumpy slag processing at Outokumpu Chrome comprises crushing, screening, wet heavy media separation and spiral washing stages. Before the crushing process water spraying is used. Water treatment is closed. The goal is maximum metal recovery and marketable metal. The recovered metal is used as a casting bed material.

4.4.4 Water treatment

Water treatment is needed in the processes with wet gas scrubbers and granulation processes. The process should be a closed system also in the sense that as many of process waters as possible are recirculated in a water treatment system. Suspended solids from the gas scrubbers must be removed before the water is recirculated. Contaminated water is normally routed to a thickener. Because of the extremely fine particles, the addition of a flocculant to the thickener is necessary to assist settling.

After the thickener(s) the settling pond(s) are used to continue settling. The settled sludge can be de-watered on vacuum filters, press filters or in centrifuges. The settled sludge is stored in deposits. To reach acceptable values for harmful components, it may be necessary in some cases to polish the bleed by routing it through sand filters or carbon filters or by adding suitable chemicals to precipitate harmful components. This will increase investment and operation costs. Cooling of the water before re-use may be necessary and can be done in cooling towers or heat exchangers.

The process water from the smelting furnace scrubbers contains cyanides. The cyanide level can be reduced by using the water for slag granulation, which leads to evaporation and oxidation of most of the cyanides. Further reduction is achieved by long retention times in large settling ponds before discharge.

In the closed furnace the PAH follows the CO-gas and is washed out in the wet scrubber. In the semiclosed furnace the PAH is incinerated above the burden in the furnace.

The emissions from water treatment are suspended solids, salts, PAH and cyanides. The precipitation of different salts may be necessary if the bleed is discharged to a fresh water recipient. The extent of polishing of the process water is dependent on the recipient.

The water treatment equipment at Outokumpu Chrome is a thickener with flocculant addition and large settling ponds. The overflow from the thickener is used in slag granulation where most of cyanides are evaporated and oxidised. Close to 90 % of the waters are recirculated in the water treatment system. The waters from the gas scrubbers and slag granulations are treated in this system.

4.4.5 Wastes

Wastes without economil utility mainly come from off-gas dusts of the submerged arc furnaces. These are transported to a depository or a landfill.

Outokumpu Chrome transfers suspended solids after the settling process to the depository.

5 Best Available Technique

High carbon ferrochromium is almost entirely produced in three-phase submerged arc furnaces with continuous operation. The furnace operation is sensitive to the particle size of the charge. Fines must be agglomerated and good lumpy ores are becoming scarce on the market. The highest possible operation time and the largest possible process unit are the basis for profitable operation and minimisation of specific emissions.

For ferrochromium production, the following techniques or combination of techniques are considered to be BAT. The order of priority and the selection of techniques will differ depending upon local circumstances:

1. Raw material handling and storage

- Raw materials are preferably stored on hard surfaces in indoor storages.
- Excessive dusting is prevented by water spraying of dry fine grained materials. For cleaning operations, bag filters are used.
- Dusts collected from the processes which can be exploited are recycled to the agglomeration processes.

2. Pre-processing

- Pretreatment methods improve chromium recoveries and reduce smelting costs.
- Wet grinding, filtering and pelletising systems are suitable for preventing dusting and producing a good chromite particle structure for the reduction process.
- Because of the external energy consumptions and emissions, the steel belt sintering furnace process is advantageous to harden pellets in order to withstand future handling.
- Low pressure wet scrubbing and bag filters are used to clean the off-gases from the sintering furnace and to dedust on dusting points. The water is recycled according to possibilities.
- Coke drying in the shaft furnace ensures the right reductant quantity in the smelting charge. Bag filter equipment is used to clean the off-gases and for dedusting.

3. Core processes

- Preheating charge materials in the shaft furnace saves specific smelting electricity consumption and increases production capacity. Off-gases are cleaned by wet scrubbing.
- Optimal smelting furnace operation is achieved by the right charge mix, depending on the raw materials. The best metal recoveries are reached with agglomerated chromites from fine materials.
- Closed smelting furnacs offer favourable possibilities for the reaction energy utilisation of carbon monoxide gas, which is a good fuel to replace other fuels in the ferrochromium production and other purposes. The CO gas is washed by high pressure venturi scrubbers. The closed furnace minimises emissions.

4. Post furnace operations

- Drills, oxygen lancing, tapping and mud-guns are used for cascade tapping operations. Hoods and ducts collect fumes and smoke from the tapping place. The cleaning equipment used is a bag filter.
- Molten ferrochromium is used directly in stainless steel production if possible. Bed and layer casting are the methods of casting ferrochromium.
- Slag granulation contributes to reduce emissions of fumes and dust.
- Bag filter technology is suitable for dedusting in the product handling process of ferrochromium. Indoor storage is preferable.
- Gravimetric processes are used for lumpy slag processing to reclaim marketable ferrochromium. The water treatment is closed. The handling steps are connected to filters.
- Processes with wet gas scrubbers and granulation equipment need a water treatment system. Process water is recirculated as much as possible. Thickeners and settling ponds are used to remove suspended solids. Flocculants assist in settling. In some cases it may be necessary to polish the bleed by using sand filters, carbon filters or suitable chemicals. The cyanide level in the smelting furnace scrubber water can be reduced by using the water for slag granulation, which leads to evaporation and oxidation of most of the cyanides.
- Wastes without economic utility are transported to a depository.

6 Emerging Techniques

The rotary hearth furnace has been investigated for prereducing chromite. The chromite fines are pelletised with coal as reductant, charged as a stationary monolayer onto the moving rotary hearth and discharged after one revolution. Potential advantages include low pellet strength requirement, rapid metallisation, low maintenance cost compared with rotary kilns and no accretion formation. The pilot tests, however, have demonstrated that there is a strong tendency for the pellets to reoxidise rapidly. Further development work is necessary. The prereduction for chromite has also been investigated in a fluidised bed. It has been attempted to lower the prereduction temperature using hydrocarbons as reductants. Deeper investigation is required.

Coal/oxygen or smelt-reduction processes rely upon the combustion of coal with oxygen or oxygen-enriched air, to provide the entire energy requirement for smelting chromite to ferrochromium. Different possibilities have been investigated by Kawasaki, NSC, NKK and Krupp. The Kawasaki STAR process is an example of a shaft furnace type. Other developments have included prereduction or preheating rotary kilns linked to converter-type vessels equipped with coal/oxygen lances for combustion and final smelting of the kiln product, to converter-type vessels only with coal/oxygen injection for total smelting. The advantage is seen in eliminating the cost of electrical energy. All the processes have some major disadvantages and problems to resolve before they can become serious competitors to large-scale ferrochromium production. There are none on commercial production-scale.

The Mintek Blobulator for granulation of ferrochromium is still at the pilot plant stage. In this process molten metal is fed into a flume comprising several parallel channels where the coolant flows. The coolant breaks the metal up into irregular “blobs” or “biscuits”. Here too, the internal heat in the blobs is used to dry the alloy.

The main difference between the granulation methods is reportedly in the size distribution. While the Blobulator is said to give blobs with more than 90 % larger than 12 mm, the other methods tend to have a sizeable fraction below 10 mm. The market for granules is still limited, since most of the steel plants mainly have handling equipment suitable for larger lumpy material.

Executive Summary

7

The ferrochromium process in Finland consists of a steel belt sintering plant, two preheating and smelting furnaces. In the sintering plant, fine concentrate is agglomerated. Sintered pellets are an excellent raw material for smelting. The charge in the smelting consists of pellets, upgraded lumpy ore, coke and quartzite.

In the sintering plant, chromite concentrate is ground and pelletised together with recycling dust prior to the sintering furnace, where hardening takes place at a temperature of 1,400°C. The thermal energy required by the furnace is obtained by combustion of coke dust added to the pellets, while carbon monoxide produced by the smelting process is employed as an additional fuel. Energy consumption is minimised by recirculating high temperature exhaust gases.

The smelting charge is preheated by burning carbon monoxide in a shaft furnace up to a temperature of 700°C. Preheating removes moisture and volatiles, while giving major savings in electricity and increasing the capacity of the smelting furnaces by 20 %.

The products obtained from the smelting furnaces, i.e. alloy and slag, are tapped into ladles. The slag is granulated and the thin slag layer remaining on top of the alloy ladles is carefully skimmed away. The alloy is cast in moulds composed of reclaimed ferrochromium. The cooled castings are crushed and screened on the product handling line to produce the commercial lots specified by the clients. A considerable part of the molten ferrochromium is transferred to the adjacent steel melting shop. The total dust emissions to air from the whole ferrochromium production are 80–120 g/tonne of ferrochromium. They come from coke drying, sintering, dosing, preheating, slag granulation and product handling processes. Correspondingly, the CO_2 emissions are 500–700 kg/t FeCr without the use of CO-gas in stainless steel production, the NO_2 emissions are 0.8–1.2 kg/t FeCr and those of SO_2, 0.3–0.5 kg/t FeCr.

The energy provided by the carbon monoxide corresponds to 45,000–50,000 tonnes of oil a year, which results in considerable savings. As CO-gas contains no sulphur, the combustion of carbon monoxide is also important from the point of view of environmental protection.

The production of ferrochromium is an energy-intensive process. All ways to minimise the specific energy consumptions are important for both production costs and environmental aspects. The reduction process is a typical high-temperature process in which the most economic and environmentally sound unit size is the largest one possible in practice.

Chromium recovery in the process is one factor which affects energy and raw material consumptions. Profitable operation and minimisation of emissions demand as high an operation time as possible. The biggest possible process equipment capacity and high operation time are the basis for a high productivity.

Because of the raw material and energy consumptions, production, emissions and operation time, the ferrochromium process at Outokumpu Chrome is considered to be the best available technique.

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Documentation page

Publisher	Finnish Environment Institut	Date June 1999
Author(s)	Marja Riekkola Vanhanen	
Title of publication	Finnish expert report on best available techniques in ferrochromium production	
Parts of publication/ other project publications		
Abstract	The aim of this BAT report is to identify available techniques for the reduction of emissions and energy use in the primary ferrochromium production in Finland. The process used consists of a steel belt sintering plant and two preheating and smelting furnaces. In the sintering plant, chromite concentrate is pelletised. The thermal energy is obtained by combustion of coke dust added to the pellets, while carbon monoxide produced by the smelting process is employed as an additional fuel. The smelting charge is preheated, which saves electricity and increases the capacity of the smelting furnaces by 20 %. A considerable part of the molten ferrochromium is transferred to the adjacent steel melting shop. The total dust emissions to air are 80–120 g/tonne of ferrochromium. They come from coke drying, sintering, dosing, preheating, slag granulation and product handling processes. Correspondingly, the CO emissions are 500–700 kg/t FeCr without the use of CO-gas in stainless steel production, the NO_2 emissions are 0.8–1.2 kg/t FeCr and those of SO_2, 0.3–0.5 kg/t FeCr. The energy provided by the carbon monoxide corresponds to 45,000–50,000 tonnes of oil a year, which results in considerable savings. Combustion of the sulphur free carbon monoxide is also important from the point of view of environmental protection.	
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Julkaisun nimi	Suomalainen asiantuntijaraportti parhaimmista käytettävissä olevista tekniikoista ferrokromin tuotannossa
Julkaisun osat/ muut saman projektin tuottamat julkaisut	
Tiivistelmä	Tässä BAT raportissa esitellään menetelmät, joita käyttämällä voidaan vähentää päästöjä ja energian kulutusta primäärisessä ferrokromin tuotannossa Suomessa. Ferrokromitehtaan muodostavat sintraamo ja sulatto. Sintraamossa kromiittirikaste pelletoidaan ja sintrataan. Prosessin energian lähteinä ovat pelletteihin lisätty hienokoksi ja sulatuksesta saatava hiilimonoksidikaasu. Sulatettava panos kuumennetaan ennen sen syöttöä valokaariuuniin. Tämä säästää sähköä ja lisää sulatusuunien tehoa 20 %. Sulatuksen jälkeen huomattava osa ferrokromista viedään sulana terästehtaalle. Loput valetaan laatoiksi, murskataan ja seulotaan. Pölypäästöt ilmaan ovat 80–120 g/t ferrokromia. Ne tulevat koksin kuivaamisesta, sintrauksesta, syötöstä, etukuumennuksesta, kuonan rakeistuksesta ja tuotteen käsittelystä. Hiilidioksidipäästöt ovat vastaavasti 500–700 kg/t ferrokromia, jos hiilimonoksidikaasua ei käytetä teräksen tuotannossa. NO_2-päästöt ovat 0,8–1,2 kg/t ferrokromia ja SO_2-päästöt 0,3–0,5 kg/t ferrokromia. Häkäkaasun poltolla korvataan vuosittain 45 000–50 000 tonnia öljyä. Rikkivapaan häkäkaasun käyttö on myös ympäristöystävällisempää kuin öljyn käyttö.
Asiasanat	Ferrokromin tuotanto, BAT
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Presentationsblad

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Publikationens titel	Finsk expert rapport om den bäst användbara tekniken i ferrokrom produktion	
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Sammandrag	Målet med den här BAT raporten är att identifiera tillgänglig teknik för reduktion av emission och energi användning i produktion av ferrokrom i Finland. Den i bruk varande processen består av en sinterenhet och ett smältverk. I sintringsenheten gör man pelletar av kromitkoncentrat. Den termiska energin erhålls av förbränning av koksdamm som tillaggts pelletarna. Som tilläggsbränsle används den kolmonoxid som produceras under smältningsprocessen. Satsen som skall smältas förvärms vilket sparar elektricitet och samtidigt ökar kapaciteten för smältugnen med 20 %. Största delen av det smultna ferrokromet transporteras till det bredvid varande stålverket. Den totala partickelemissonen i luften är 80 till 120 g/tonn ferrokrom. Particklar uppstår under torkning av koks, sintring, dosering, förvärmning, grannulering av slaggen och från produktbehandlingsprocesser. Om man inte använder kolmonoxidgasen för stålproduktionen, är koldioxidemissionen 500 till 700 kg/tonn av ferrokrom. NO_2-emissionen är 0,8–1,2 kg/tonn ferrokrom och SO_2-emissionen är 0,3–0,5 kg/tonn ferrokrom. Energin som kan tas tillvara från kolmonoxiden motsvarar 45 000 till 50 000 tonn av olja per år, vilket resulterar i betydande inbesparingar. Förbränning av den svavelfria kolmonoxiden är också ur miljösynpunkt av vikt.	
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